CLEAR CHANNEL ACCESS METHODS, APPARATUSES, MEDIA AND SIGNALS

FIELD OF THE INVENTION

The present invention relates to network communications, and more particularly, to methods, apparatuses, media and signals for providing clear channel access on a network.

BACKGROUND OF THE INVENTION

Carriers or operators of high-bandwidth networks, such as optical networks, typically sell network access to their customers, which often include telephone companies or other telecommunications service providers. For example, an operator of an optical network segment extending between two major cities may receive a number of communications signals or channels from a number of respective customers at an originating city, which are then multiplexed or combined into a single higher-speed optical communications signal. The higher-speed signal is then relayed to the destination city, where it is then demultiplexed or split apart into its component signals, which are then separately provided to the respective customers' facilities in the destination city.

Each communications signal initially provided by a customer of the network operator typically includes a payload portion in which the actual "live" communications traffic is stored, and further includes a transport overhead portion which is used by the customer for various purposes, including monitoring the occurrence of transmission errors that may arise on the customer's own communications equipment and facilities.

However, as each customer's communications signal is carried over the network operator's optical network segment extending between the two cities,

it generally passes through a number of different network elements at which it is necessary for the network operator's equipment to over-write the customer's transport overhead data, in order for the network operator to monitor the occurrence of errors on the optical network segment. Accordingly, when the communications signal is relayed to the customer at the destination city, much of the customer's transport overhead information has been destroyed. This may interfere with or destroy the ability of the customer to monitor aspects of its own facilities, such as the occurrence of errors on the customer's equipment in the vicinity of the originating city, for example.

Accordingly, it would be desirable, from the point of view of some such customers, for the network operator to be able to provide a "clear channel" across the network segment, or in other words, for the network operator to pass transport overhead information to the customer at the destination city in such a way that the customer's ability to monitor the occurrence of errors on its own facilities would not be affected by anything that may have occurred over the operator's network segment, as if the network segment did not exist.

One approach to a similar problem involves providing special dedicated facilities on the network segment, including a transparent multiplexer or combiner for example, along with special line facilities that preserve portions of the customer's incoming overhead information for reconstruction at the destination, so that the preserved overhead is effectively passed through the network segment transparently. Disadvantageously, however, such dedicated facilities are not capable of combining a mixture of transparent and non-transparent channels into a single optical signal, with the result that such facilities are useful only in circumstances where all of the customers whose signals are to be combined together desire transparent access to the network segment. In addition, if the individual signals that have been multiplexed into the single optical signal are not all destined for the same network node or location, it is not possible for these dedicated facilities to perform the usual seamless extraction of the individual signal at the intervening node at which the individual signal is to be dropped off. Rather, the entire signal must be

demultiplexed in order to extract the individual signal that is to be dropped off, and the individual signals that are destined for subsequent network locations must be re-multiplexed or combined back into a new optical signal. This results in significantly increased equipment costs, as additional demultiplexers and re-multiplexers must be provided at any such intervening network node for signals that are merely passing through the network node. Accordingly, these dedicated facilities are not well-suited to accommodating the differing needs of different customers, and result in significantly increased equipment costs for network operators.

Accordingly, there is a need for an improved way of providing clear channel access.

SUMMARY OF THE INVENTION

Aspects of the present invention address the above needs by providing a method and an apparatus for providing clear channel access on a network. The method involves receiving a communication signal from a remote network element, the communication signal including a previous transport overhead (PTOH) portion indicative of transport overhead contents of the communication signal prior to arrival at the remote network element, and a previous path error (PPE) portion indicative of path errors present in the communication signal at the remote network element. The method further involves modifying a transport overhead portion of the communication signal in response to the PTOH and PPE portions. The apparatus includes a receiver operable to receive the communication signal, and further includes a processor circuit in communication with the receiver and configured to modify the transport overhead portion.

Advantageously, by modifying the transport overhead portion of the communication signal in response to both the previous transport overhead portion and the previous path error portion, a clear channel may be provided, allowing a customer who then receives the communication signal to process the

transport overhead portion as if it had not been affected by its passage across the network.

In addition, the above method and apparatus permit implementation in network configurations other than dedicated clear channel systems, thereby allowing the communication signal to pass through normal network elements such as Line Terminating Equipment, Add/Drop Multiplexers, or Ring configurations, for example. Thus, the disadvantages associated with dedicated clear channel facilities may be avoided, if desired. For example, if desired, the method or apparatus may be implemented in typical network configurations, allowing both clear channel and non-clear channel communication signals to be multiplexed together, and allowing individual signals to be dropped off at intervening network nodes in the usual manner, without the need to demultiplex and re-multiplex the individual signals that are passing through to a subsequent network node.

The communication signal may include a plurality of component signals, in which case modifying the transport overhead portion preferably involves calculating, for each of the component signals, a difference between path errors present in the component signal and path errors present in the component signal at the remote network element. Modifying the transport overhead portion may then include calculating a sum of the differences of each of the component signals, and adding the sum of the differences to at least some contents of the PTOH portion. Advantageously, these additional features further improve the transparency of the clear access channel.

A further aspect of the invention provides a computer-readable medium for providing codes for directing a processor circuit to modify the transport overhead portion in response to the PTOH and PPE portions. Similarly, another aspect of the invention provides a signal embodied in a carrier wave, the signal including code segments for directing a processor circuit to modify the transport overhead portion in response to the PTOH and PPE portions.

An additional aspect of the invention relates to an apparatus for providing clear channel access on a network, the apparatus including provisions for carrying out the above method.

In accordance with further aspects of the invention, there are provided a method and an apparatus for providing clear channel access on a network. The method involves inserting into a communication signal received at a network element, a previous transport overhead (PTOH) portion indicative of transport overhead contents of the communication signal prior to arrival at the network element, and a previous path error (PPE) portion indicative of path errors present in the communication signal at the network element. The method further involves transmitting the communication signal to a remote device. The apparatus includes a processor circuit configured to insert the PTOH and PPE portions into the communication signal, and a transmitter in communication with the processor circuit and operable to transmit the communication signal to a remote device.

Inserting the PTOH and PPE portions into the communication signal in the above manner, and transmitting the signal to the remote device, allows the remote device to use the communication signal to provide clear channel access, as described above, resulting in similar advantages to those mentioned above.

If desired, inserting the PPE portion may involve performing Tandem Connection Monitoring (TCM) or, advantageously, may involve a variation thereof. For example, if desired, rather than inserting the PPE portion into the Z**5** byte in accordance with standard TCM, the PPE portion may be inserted into an unused portion of the path overhead portion, which may include either the Z**3** or the Z**4** byte of a Synchronous Optical NETwork (SONET) path overhead portion, for example. Advantageously, by selecting an unused portion of the path overhead for insertion of the PPE, transparency of the channel is further improved, as the customer's ability to use other parts of the path overhead, such as the Z**5** byte for example, is not compromised. This is particularly advantageous if the customer wishes to perform Tandem Connection Monitoring of the customer's own facilities using the Z**5** byte (also referred to as the N**1** byte when used for TCM), as the insertion of the PPE

portion into the Z3 or Z4 byte would therefore not over-write the customer's own TCM information stored in the Z5 byte.

A further aspect of the invention relates to a computer-readable medium for providing codes for directing a processor circuit to cause the above method to be carried out. Similarly, another aspect provides a signal embodied in a carrier wave, the signal including code segments for directing a processor circuit to cause the method to be carried out. A further aspect relates to an apparatus for providing clear channel access on a network, the apparatus including provisions for carrying out the method.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate embodiments of the invention,

Figure **1** is a block diagram of an apparatus for providing clear channel access on a network, according to a first embodiment of the invention;

Figure **2** is a block diagram of an apparatus for providing clear channel access on a network, according to a second embodiment of the invention;

Figure **3** is a block diagram of a system for providing clear channel access on a network, according to a third embodiment of the invention;

Figure **4** is a block diagram of a transport control subsystem (TCS) of a first network element shown in Figure **3**;

Figure **5** is a block diagram of a transport control subsystem (TCS) of a second network element shown in Figure **3**;

Figure **6** is a flowchart of a previous transport overhead (PTOH) and previous path error (PPE) insertion thread executed by the TCS shown in Figure **4**;

Figure **7** is a fragmented tabular representation of a communication signal as modified in response to execution of the PTOH and PPE insertion thread shown in Figure **6**; and

Figure **8** is a flowchart of a transport overhead modification thread executed by the TCS shown in Figure **5**.

DETAILED DESCRIPTION

Referring to Figure **1**, an apparatus for providing clear channel access on a network **20** according to a first embodiment of the invention is shown generally at **22**. The apparatus **22** includes a processor circuit **24** configured to insert into a communication signal **26** received at a network element **28**, a previous transport overhead (PTOH) portion **30** indicative of transport overhead contents **32** of the communication signal **26** prior to arrival at the network element **28**, and a previous path error (PPE) portion **34** indicative of path errors **36** present in the communication signal **26** at the network element **28**. The apparatus **22** further includes a transmitter **38** in communication with the processor circuit **24**, operable to transmit the communication signal **26** to a remote device **40**.

Referring to Figure **2**, an apparatus for providing clear channel access on a network **42** according to a second embodiment of the invention is shown generally at **44**. The apparatus **44** includes a receiver **46** operable to receive a communication signal **48** from a remote network element **50**. The communication signal **48** includes a previous transport overhead (PTOH) portion **52** indicative of transport overhead contents of the communication signal **48** prior to arrival at the remote network element **50**, and also includes a previous path error (PPE) portion **54** indicative of path errors present in the

communication signal at the remote network element **50**. The apparatus **44** further includes a processor circuit **56** in communication with the receiver **46**. The processor circuit **56** is configured to modify a transport overhead portion shown generally at **58** of the communication signal **48** in response to the PTOH and PPE portions **52** and **54**.

System

Referring to Figures **1**, **2** and **3**, a system for providing clear channel access on a network **60** according to a third embodiment of the invention is shown generally at **62** in Figure **3**. The system **62** includes a first apparatus, which in this embodiment is a first network element **64** similar to the apparatus shown at **22** in Figure **1**, as well as a second apparatus, which in this embodiment is a second network element **66** similar to the apparatus shown at **44** in Figure **2**. The first and second network elements are in communication with each other over the network **60**.

Referring to Figure **3**, in this embodiment, the network **60** includes an optical network in accordance with Synchronous Optical NETwork (SONET) standards, although alternatively, other types of networks may be substituted. More particularly, in this embodiment the network **60** is an Optical Carrier (OC)-**192** network, and includes a plurality of network elements interposed between the network elements **64** and **66**, such as those shown at **68** for example. In this embodiment the interposed network elements include pluralities of both section terminating equipment and line terminating equipment devices.

The first network element **64** in the present embodiment includes a first Line Terminating Equipment (LTE) **70**, having various capabilities such as cross-connecting, add/drop multiplexing, etc. The first LTE **70** is in communication with an OC-**48** optical pipe **72**, over which it receives a communication signal shown generally at **74**, that is to be multiplexed onto the OC-**192** network **60**, from a first customer equipment **76**.

The first network element **64** includes a processor circuit shown generally at **78**, configured to insert into the communication signal **74** received at the network element **64**, a previous transport overhead (PTOH) portion **80** indicative of transport overhead contents **82**, which in this embodiment are transport overhead parity error portions, of the communication signal **74** prior to arrival at the network element **64**, and a previous path error (PPE) portion **84** indicative of path errors **86** present in the communication signal **74** at the network element **64**. The first network element **64** further includes a transmitter **87** in communication with the processor circuit **78** and operable to transmit the communication signal **74** to a remote device, which in this embodiment is the second network element **66**.

In this embodiment, the processor circuit **78** includes a first transmit/receive overhead processor (TROHP) **88**, a first Synchronization Driver Receiver (SYDR) device **90** and a first transport control subsystem (TCS) **92**. More particularly, in this embodiment the TROHP **88** includes a TROHP**4** Application Specific Integrated Circuit (ASIC), and the SYDR device **90** includes four individual SYDR**4** TriFEC ASICs, manufactured by Nortel Networks Limited of Montreal, Canada. Generally, the TROHP**4** ASIC is a section / line overhead processor operable to monitor and extract section and line error counts along with the other section and line overhead portions of a Synchronous Transport Signal (STS) communication signal. In this regard, the TROHP **88** includes a PM binning register **89** for binning or accumulating section (B**1**) parity errors, and a signal degrade binning register **91** for binning or accumulating line (B**2**) parity errors. Similarly, the SYDR device **90** processes path errors and path overhead, and also acts as a path data/clock synchronizer for handling timing discrepancies. Alternatively, however, other suitable circuits may be substituted.

The transmitter **87** includes a multiplexer module, a laser modulator and a laser (not shown). The first network element **64** also contains elements (not shown) that are well-known components of such network elements and are therefore omitted in Figure **3** for clarity.

In this embodiment, the second network element **66** includes a second Line Terminating Equipment (LTE) **94**, having various capabilities similar to those of the first LTE **70**, including cross-connecting, add/drop multiplexing, etc. The second LTE **94** is in communication with a second OC-**48** optical pipe **96**, over which it transmits a modification of the communication signal **74**, to a second customer equipment **98**.

The second network element **66** includes a receiver **100** operable to receive a communication signal from a remote network element, which in this embodiment includes the communication signal **74** received from the first network element **64**, and thus, the communication signal includes the PTOH portion **80** and the PPE portion **84**. The second network element **66** further includes a processor circuit **102** in communication with the receiver **100**. The processor circuit **102** is configured to modify a transport overhead portion shown generally at **104** of the communication signal **74** in response to the PTOH and PPE portions **80** and **84**.

More particularly, in this embodiment the processor circuit **102** includes a second TROHP **106**, a second SYDR device **108** and a second TCS **110**, similar to those of the first processor circuit **78**, the SYDR device **108** comprising four individual SYDR**4** ASICs, for example. Also in this embodiment, the receiver **100** includes a demultiplexer module (not shown). The second network element **66** also contains elements (not shown) that are well-known components of such network elements and are therefore omitted in Figure **3** for clarity.

In this embodiment, a Tandem Connection Maintenance (TCM) connection is established between the first and second network elements **64** and **66**, as defined in accordance with The American National Standards Institute (ANSI) standard T**1.105.05-1994**, "Synchronous Optical Network (SONET): Tandem Connection Maintenance", which is incorporated herein by reference. Thus, in the present embodiment, the first network element **64** acts as a tandem connection originating element and the second network element **66** acts as a tandem connection terminating element.

In this regard, although one-way communication signals are primarily described herein for ease of illustration, it will be appreciated that embodiments of the invention are equally applicable to bi-directional communication, in which each one of the first and second network elements **64** and **66** performs the functions of the first network element **64** in the transmit direction, and the functions of the second network element **66** in the receive direction.

First processor circuit TCS

Referring to Figures **3** and **4**, the first TCS of the first processor circuit **78** is shown generally at **92** in Figure **4**. In this embodiment, the first TCS **92** includes a first microcontroller **120**, in communication with a first program memory **121**, a first working memory **124**, and a first input/output (I/O) device **126** via which the TCS **92** is in communication with the TROHP **88**, the SYDR device **90**, and with other components of the network element **64**.

The program memory **121**, which in this embodiment includes a non-volatile memory such as a FLASH or EEPROM for example, stores various routines, subroutines and threads for execution by the microcontroller **120**.

Generally, in the present embodiment the program memory **121** acts as a computer-readable medium for providing codes for directing the processor circuit **78** to insert into the communication signal **74** received at the network element **64**, the previous transport overhead (PTOH) portion **80** indicative of the transport overhead contents **82** of the communication signal **74** prior to arrival at the network element **64**, and the previous path error (PPE) portion **84** indicative of the path errors **86** present in the communication signal **74** at the network element **64**, and to transmit the communication signal **74** to a remote device, which in this embodiment is the second network element **66**. More particularly, in this embodiment the program memory stores a PTOH and PPE insertion thread **128**, for directing the processor circuit **78** to insert the PTOH portion **80** and PPE portion **84** shown in Figure **3** into the communication signal **74**. Alternatively, however, it will be appreciated that

the PTOH and PPE insertion thread **128** may be omitted if hardware components of the processor circuit **78**, such as the TROHP **88** and/or the SYDR device **90** for example, are pre-configured to insert the PTOH and/or PPE portions into the communication signal **74**. Similarly, any other suitable computer-readable medium may be substituted.

In addition, it will be appreciated that the program memory **121** merely provides one way of generating a signal embodied in a carrier wave, the signal including code segments for directing the processor circuit to insert the PTOH and PPE portions **80** and **84** into the communication signal in the above manner and to transmit the communication signal to a remote device. Alternatively, other types of media, signals, or ways of generating such signals may be substituted.

In this embodiment, the program memory **121** also includes a PTOH header values register **122**, in which unique PTOH header values are stored, as discussed in greater detail below. The program memory **121** also stores an index look-up table **123**, for use by the microcontroller in executing the PTOH and PPE insertion thread. In addition, the program memory **121** stores routines (not shown, not part of this invention) for directing the processor circuit **78** to execute conventional network element functionality such as LTE, ADM and cross-connect functionality, for example.

In this embodiment, the PTOH and PPE insertion routine **128** configures the microcontroller **120** to define various registers in the first working memory **124**, including a section errors register **125** for storing an indication of accumulated section (B**1**) parity errors in the incoming communication signal **74** received at the first network element, a line errors register **127** for storing an indication of accumulated line (B**2**) parity errors in the incoming communication signal, and a PTOH register **129** for storing the PTOH portion **80** that is to be inserted into the transport overhead portion **104** of the communication signal **74**.

<u>Second processor circuit TCS</u>

Referring to Figures **3** and **5**, the second TCS of the second processor circuit **102** is shown generally at **110** in Figure **5**. In this embodiment, the second TCS **110** includes a second microcontroller **130**, in communication with a second program memory **132**, a second working memory **134**, and a second input/output (I/O) device **136** via which the TCS **110** is in communication with the TROHP **106**, the SYDR device **108**, and with other components of the network element **64**.

The program memory **132**, which in this embodiment includes a non-volatile memory such as a FLASH or EEPROM for example, stores various routines, subroutines and threads for execution by the microcontroller **130**.

Generally, the program memory **132** acts as a computer-readable medium for providing codes for directing the processor circuit **102** to modify the transport overhead portion **104** of the communication signal **74** received from the network element **64**, in response to the PTOH portion **80** of the communication signal indicative of the transport overhead contents **82** of the communication signal prior to arrival at the remote network element **64**, and the PPE portion **84** of the communication signal indicative of the path errors **86** present in the communication signal at the remote network element. More particularly, in this embodiment the program memory **132** stores a transport overhead modification thread **138**, for directing the processor circuit **102** to modify the transport overhead portion **104** of the communication signal **74** shown in Figure **3**, in response to the PTOH portion **80** and the PPE portion **84**. Alternatively, however, any other suitable computer-readable medium may be substituted.

In addition, it will be appreciated that the program memory **132** merely provides one way of generating a signal embodied in a carrier wave, the signal including code segments for directing the processor circuit to modify the transport overhead portion in response to the PTOH and PPE portions in the above manner. Alternatively, other types of media, signals, or ways of generating such signals may be substituted.

In this embodiment, the program memory **132** also stores index look-up tables shown generally at **139**, which in this embodiment include a forward index look-up table **140**, a reverse index look-up table **142**, and a hardware configuration look-up table **144**, for use by the microcontroller **130** in executing the transport overhead modification thread **138**.

The program memory **132** also stores routines (not shown, not part of this invention) for directing the processor circuit **102** to execute conventional network element functionality such as LTE, ADM and cross-connect functionality, for example.

The routines stored in the program memory **132** direct the processor circuit **102** to define various registers in the second working memory **134**, including a differences register **202**, a sum of differences register **203**, a PTOH register **204** including a previous section overhead field **205** and a previous line overhead field **206**, an outgoing section error register **207** and an outgoing line error register **208**. Such registers are discussed in greater detail below.

<u>OPERATION</u>

Referring to Figure **3**, in this embodiment the first and second network elements **64** and **66** are configured, via a manual user provisioning operation, to transport the communication signal **74** received from the first customer equipment **76** to the second customer equipment **98** as a clear channel. (Alternatively, however, if desired, the first and second network elements may be quickly and easily configured by a similar user provisioning operation to transport the communication signal **74** in a conventional (non-clear) manner.)

<u>First Network Element</u>

Referring to Figures **3**, **4**, **6** and **7**, the PTOH and PPE insertion thread is shown generally at **128** in Figure **4**. Generally, the PTOH and PPE insertion thread **128** configures the processor circuit **78** to insert the PTOH and PPE portions **80** and **84** into the communication signal **74** shown in Figure **3**, and

to transmit the communication signal to a remote device, which in this embodiment is the second network element **66**.

The PTOH and PPE insertion thread **128** begins with a first block **150** of codes, which generally configures the processor circuit **78** to calculate the PPE portion **84** in response to path parity errors present in the communication signal **74** at the network element **64**, and to insert the PPE portion into a path overhead portion of the communication signal, or more particularly, into an unused portion of the path overhead portion. In this embodiment block **150** first directs the microcontroller **120** of the processor circuit **78** to signal the SYDR device **90**, in order to configure the SYDR device to insert the PPE portion **84** into the unused path overhead portion of the communication signal **74**.

In this regard, referring to Figures **6** and **7**, a fragmented representation of the communication signal is shown generally at **74** in Figure **7**. In this embodiment, the communication signal **74** is an OC-**48** SONET communication signal, but is illustrated in Figure **7** with reference to its electrically equivalent Synchronous Transport Signal (STS)-**48** signal. More particularly, the communication signal **74** includes the transport overhead (TOH) portion shown generally at **104** and a synchronous payload envelope (SPE) portion shown generally at **164**. The SPE **164** includes a payload portion **166** and a path overhead portion **168**.

The transport overhead portion **104** includes a plurality of unused transport overhead portions, such as unused transport overhead portions shown generally at **162** represented by shaded regions in Figure **7**, for example. Such shaded regions generally correspond to unused time-slots of transport overhead bytes that are defined only for the first STS-**1** component of an STS-N signal, and are not defined for the remaining STS components of the signal. Thus, it is not necessary to terminate any such bytes at section- or line-terminating equipment and accordingly, in the present embodiment, any section- or line-terminating equipment devices interposed on the network **60** between the first and second network elements **64** and **66**, are configured to

transparently pass such unused time-slot bytes. Similarly, the path overhead portion **168** includes a plurality of unused path overhead portions, such as a plurality of Z**3** bytes shown generally at **174** or a plurality of Z**4** bytes shown at **176**, for example. Although these unused path overhead portions are not unused time-slots, they are nevertheless unused, as the Z**3** and Z**4** bytes are presently unallocated growth bytes of SONET. It will be appreciated that the entire SPE **164** is transparently passed between the network elements **64** and **66**, as there is no path terminating equipment located therebetween.

Referring to Figures **3** and **7**, it will be appreciated that Tandem Connection Maintenance (TCM) according to the ANSI T**1.105.05-1994** standard involves, for each interleaved STS-**1** component of an STS-N signal frame, calculating the number of path errors **86** shown in Figure **3**. This is achieved by counting the number of parity errors in the SPE portion **164** of the preceding STS-**1** component before scrambling, using a bit interleaved parity **8** code with even parity. In other words, the number of parity errors is counted using the same method that would be used by path originating equipment (not shown) to calculate an initial B**3** path error monitoring byte **170** of the path overhead **168**. This counted number of parity errors will differ from the B**3** byte **170** if any bit errors in the relevant (preceding STS-**1**) SPE portion **164** have occurred since the signal **74** was initially generated and transmitted by the customer's path originating equipment. Accordingly, the contents of the B**3** byte **170** of a given STS-**1** component are subtracted from the number of parity errors counted over the previous STS-**1** component, to yield the number of path errors **86** present in the previous STS-**1** component of the communication signal **74** at the network element **64**, or in other words, the number of new parity errors that have arisen in that component between the time the B**3** byte was generated at the customer's path originating equipment, and the time the signal **74** arrived at the first network element **64**. In this embodiment, it is this latter resulting number of path errors **86** that is to be inserted into the communication signal **74** as the previous path error (PPE) portion **84** shown in Figure **3**.

TCM further involves storing the number of path errors **86** in bits **1-4** of a Z**5** byte **172** in the path overhead portion **168**. Finally, TCM involves compensating the B**3** byte **170**, by adjusting the value of the B**3** byte to take into account the parity change resulting from writing the number of path errors **86** to the Z**5** byte **172**.

If desired, block **150** may simply direct the microcontroller **120** of the processor circuit **78** to configure the SYDR device **90** to perform the above-noted conventional TCM steps to insert the number of path errors **86** into the first **4** bits of the Z**5** byte **172**, with the result that the Z**5** byte **172** becomes the PPE portion **84**, and to compensate the B**3** byte **170** for the parity change resulting from the insertion.

Advantageously, however, in the present embodiment block **150** differs from conventional TCM, in that it configures the processor circuit **78** to insert the PPE portion **84** into at least one of a Z**3** and a Z**4** byte of a Synchronous Optical NETwork (SONET) path overhead portion. More particularly, in this embodiment block **150** directs the processor circuit **78** to configure the SYDR device **90** to write the number of path errors **86** to a Z**3** byte **174** of the path overhead portion **168** rather than to the Z**5** byte **172**. Thus, in this embodiment the PPE portion **84** includes the Z**3** byte **174** following such writing by the SYDR device. In this regard, it is possible that the customer, from whom the OC-**48** communication signal **74** is originating, may wish to use the Z**5** byte **172** to perform TCM across the customer's own equipment, such as between the first and second customer equipment **76** and **98**, for example. Therefore, by writing the number of path errors **86** to the Z**3** byte **174** which is presently an unused SONET growth byte, the SPE **164** is effectively transparently passed to the customer (apart from the unused Z**3** byte), without interfering with the customer's ability to use path overhead bytes such as Z**5** for TCM, for example. Alternatively, block **150** may direct the processor circuit **78** to configure the SYDR device **90** to write the number of path errors **86** to a different byte, such as a Z**4** byte **176** which is also presently an unused growth byte, resulting in similar advantages.

In any of the above three variations (i.e., writing the number of path errors **86** to Z**5**, Z**3** or Z**4**), block **150** further configures the processor circuit **78** to adjust a path parity error portion of the communication signal to compensate for insertion of the PPE portion into the path overhead portion. More particularly, block **150** directs the processor circuit **78** to configure the SYDR device **90** to compensate the B**3** byte **170** for the parity change resulting from writing the number of path errors **86** to the path overhead portion **168**, in accordance with the TCM standard B**3** compensation equation.

Referring to Figures **3** and **6**, once initially configured in the above manner at block **150**, the SYDR device **90** continues to continuously insert the PPE portion **84** into successive frames of the communication signal **74** received at the network element **64**. Thus, in this embodiment the PPE insertion is performed by hardware, namely, by the SYDR device. Alternatively, however, software methods, such as a software simulation of TCM to effectively insert the PPE portion for example, may be substituted if desired.

Referring to Figures **3**, **4**, **6** and **7**, block **180** then configures the processor circuit **78** to insert the PTOH portion **80** into the transport overhead portion **104** of the communication signal, or more particularly, into the unused portion **162** of the transport overhead portion **104**. In this embodiment the unused portion is an unused time-slot of the transport overhead portion **104**, such as those described earlier herein in connection with the shaded regions of Figure **7**, for example. More particularly still, in this embodiment the unused time-slot is the STS#**9** time-slot of the K**2** byte shown in Figure **7**, as discussed in greater detail below. Alternatively, however, one or more other portions of the transport overhead portion may be substituted, although unused portions are preferred for this purpose.

In this embodiment, block **180** achieves such insertion by first directing the microcontroller **120** of the processor circuit **78** to cooperate with the TROHP **88** to insert the PTOH portion **80** into the transport overhead portion **104** of the communication signal **74**. In this embodiment the PTOH portion **80** is generated and inserted into the transport overhead portion **104** by software

methods, or more particularly, in response to a continuous execution of block **180** by the microcontroller **120**. More particularly, in this embodiment block **180** configures the processor circuit **78** to calculate the PTOH portion **80** in response to the previous transport overhead contents **82** of the communication signal **74** prior to its arrival at the first network element **64**, over a previous **100** millisecond interval, rather than passing such transport overhead contents directly. Alternatively, however, if suitable hardware components are available, block **180** may direct the microcontroller to configure such hardware components to continuously insert the PTOH portion **80**.

In this embodiment, to generate the PTOH portion **80**, block **180** first configures the processor circuit **78** to count a number of transport parity errors present in the communication signal **74** prior to its arrival at the network element. More particularly, block **180** directs the microcontroller **120** to sample the contents of the PM binning register **89** of the TROHP **88**, once per second, to store a value equal to one-tenth of the contents of the PM binning register **89** in the section errors register **125** of the first working memory **124**, and to reset the contents of the PM binning register. Thus, as the PM binning register of the TROHP **88** stores an accumulated number of section parity errors in the incoming communication signal **74** received at the first network element **64**, the contents of the section errors register **125** at any given time represents the average number of section parity errors in the incoming communication signal **74** in each of the ten **100** ms sub-intervals in the one-second interval preceding the most recent sampling of the PM binning register **89**. As the PM binning register contents are incremented by the TROHP **88** in response to parity discrepancies between the entire contents of a given STS-**48** frame of the communication signal **74** and the B**1** byte of the subsequent STS-**48** frame, the contents of the section errors register **125** are, in that sense, indicative of the previous transport overhead contents **82**, or more particularly of the section (B**1**) parity error bytes of the communication signal **74**

Each time a value equal to one-tenth the sampled contents of the PM binning register **89** is stored in the section errors register **125** in the above manner, block **180** further directs the microcontroller **120** to store a value corresponding to the contents of the section errors register in a section field of the PTOH register **129**, for insertion into the transport overhead portion of the communication signal **74**. More particularly, if the contents of the section errors register **125** are less than **126**, block **180** configures the processor circuit **78** to effectively set the PTOH portion **80** equal to the counted number of transport parity errors (in this example, section parity errors) present in the communication signal prior to its arrival at the first network element **64**. More particularly still, block **180** directs the microcontroller **120** to store such contents of the section errors register **125**, as a raw section error value, in the section field of the PTOH register **129**. If desired, this value may be further "massaged", by rounding it up to the nearest multiple of eight for example, prior to storing it in the section field of the PTOH register. Such massaging may be useful if the TROHP at the second network element **66** is constrained in its ability to corrupt certain numbers of bits in the outgoing communication signal.

However, if the contents of the section errors register **125** are greater than or equal to **126** (i.e. if the most recently sampled PM binning register **89** contents were greater than or equal to **1255**), block **180** configures the processor circuit **78** to effectively set the PTOH portion **80** equal to an index value indicative of the counted number of transport parity errors (in this example, section parity errors) present in the communication signal **74** prior to its arrival at the first network element **64**. More particularly, block **180** directs the microcontroller **120** to use the contents of the section errors register **125** to search the index look-up table **123**, to locate an index number corresponding to such contents, and to store the located index number in the section field of the PTOH register **129**. In this regard, Table **1** illustrates an exemplary index look-up table. The middle column showing equivalent bit error rates (BERs) is not used in the present embodiment, but is shown below for illustrative purposes.

Table **1**

(Exemplary Index Look-up Table **123**)

X = contents of section errors register **125**; -or - X = contents of line errors register **127**	Equivalent bit error rate of incoming OC-**48** comm. signal **74** (rounded)	Index value (hex)
126 $\leq$ X $\leq$ 186	**5** x **10**$^{-7}$	**0D**
187 $\leq$ X $\leq$ 622	**1** x **10**$^{-6}$	**0E**
623 $\leq$ X $\leq$ 1866	**5** x **10**$^{-6}$	**0F**
1867 $\leq$ X $\leq$ 6220	**1** x **10**$^{-5}$	**10**
6221 $\leq$ X $\leq$ 18662	**5** x **10**$^{-5}$	**11**
18663 $\leq$ X $\leq$ 62207	**1** x **10**$^{-4}$	**12**
62208 $\leq$ X $\leq$ 186623	**5** x **10**$^{-4}$	**13**
186624 $\leq$ X $\leq$ 622079	**1** x **10**$^{-3}$	**14**
622080 $\leq$ X	AIS	FF

Upon locating the corresponding index number, the microcontroller **120** is directed by block **180** to store the index number in the section field of the PTOH register **129**. Alternatively, however, other index tables, or more broadly, any other suitable approximation method may be used to approximate such large error values with a single byte, or as a further alternative, more than one byte of stolen overhead may be used to transport such large error values, if desired.

Similarly, in this embodiment block **180** also configures the processor circuit **78** to count a second number of transport parity errors, or more particularly, line parity errors, present in the communication signal **74** prior to its arrival at the first network element **64**. To achieve this, block **180** directs the microcontroller **120** to effectively sample the contents of the signal degrade binning register **91** of the TROHP **88** once every **100** milliseconds, to store the contents of the signal degrade binning register **91** in the line errors register

127 of the first working memory **124**, and to reset the contents of the signal degrade binning register. (If desired, the signal degrade binning register **91** may be sampled more frequently, such as three times over each **100** ms interval for example, and the sampled contents may be accumulated in a separate register (not shown) which is copied to the line errors register **127** every **100** ms and is then reset to continue accumulating such more frequent samples.) Thus, as the signal degrade binning register **91** of the TROHP **88** stores an accumulated number of line parity errors in the incoming communication signal **74** received at the first network element **64**, the contents of the line errors register **127** at any given time represents the total number of line parity errors in the incoming communication signal **74** in the **100** ms interval preceding the most recent sampling of the signal degrade binning register. As the signal degrade binning register contents are incremented by the TROHP **88** in response to parity discrepancies between the line overhead and synchronous payload envelope of a given STS-**1** component of an STS-**48** frame of the communication signal **74** and the B**2** byte of the subsequent STS-**1** component, the contents of the line errors register **127** are, in that sense, indicative of the previous transport overhead contents **82**, or more particularly of the line (B**2**) parity error bytes of the communication signal **74**

Each time the line errors register **127** is updated in the above manner in response to the sampled contents of the signal degrade binning register **91** over a given **100** ms interval, block **180** further directs the microcontroller **120** to store a value corresponding to the contents of the line errors register in a line field of the PTOH register **129**, for insertion into the transport overhead portion of the communication signal **74**. More particularly, if the contents of the line errors register **127** are less than **126**, block **180** configures the processor circuit **87** to effectively set the PTOH portion **80** equal to the counted number of transport parity errors (in this example, line parity errors) present in the communication signal **74** prior to arrival at the first network element **64**. To achieve this, block **180** directs the microcontroller **120** to store such contents of the line errors register **127**, as a raw line error value, in

the line field of the PTOH register **129**. As with the section field, the contents of the line errors register **127** may be "massaged" if desired, by rounding such contents up to the nearest multiple of eight for example, prior to storing such contents in the line field of the PTOH register **129**.

However, if the contents of the line errors register **127** are greater than or equal to **126**, block **180** configures the processor circuit **78** to effectively set the PTOH portion **80** equal to an index value indicative of the counted number of transport parity errors (in this example, line parity errors). More particularly, block **180** directs the microcontroller **120** to use the contents to search the index look-up table **123** shown in Table **1** above, to locate an index number corresponding to the value, and to store the located index number in the section field of the PTOH register **129**.

Upon locating the corresponding index number, the microcontroller **120** is directed by block **180** to store the index number in the line field of the PTOH register **129**.

In addition, block **180** directs the microcontroller **120** to cooperate with the TROHP to insert the contents of the PTOH register **129** into the unused portion **162** of the transport overhead portion of the communication signal **74**. More particularly, in this embodiment, block **180** directs the microcontroller **120** to effectively transmit the contents of the section field and the line field of the PTOH register **129** ten times per second, in a sufficiently slow manner as to be detectable by software at the second network element **66**, as follows.

In this regard, block **180** configures the processor circuit **78** to insert a PTOH header value in the communication signal, preceding the PTOH portion **80**, to identify the PTOH portion. More particularly, within each successive **100** ms interval, block **180** directs the microcontroller **120** to cooperate with the TROHP **88** to insert a unique B**2** header byte into the STS#**9** time-slot of the K**2** byte for a first sub-interval of **25** ms (or in other words, for **200** successive frames). In this embodiment, the unique B**2** header byte is obtained from the PTOH header values register **122**, and serves to indicate to the second

network element **66** that the byte that is to follow in the next **25** ms sub-interval is a previous transport overhead portion, indicative of previous line (B**2**) parity error contents of the communication signal **74** prior to its arrival at the first network element **64**. Block **180** then directs the microcontroller **120** to cooperate with the TROHP **88** to insert the contents of the line field of the PTOH register **129** into the STS#**9** time-slot of the K**2** byte for a second sub-interval of **25** ms (i.e. for the next **200** successive data frames). This allows sufficient time for the contents of the line field to be detected at the second network element **66**.

Similarly, block **180** then directs the microcontroller **120** to cooperate with the TROHP **88** to insert a unique B**1** header byte into the STS#**9** time-slot of the K**2** byte for a third sub-interval of **25** ms (i.e. for the next **200** successive frames). In this embodiment, the unique B**1** header byte is obtained from the PTOH header values register **122**, and serves to indicate to the second network element **66** that the byte that is to follow in the next **25** ms sub-interval is a previous transport overhead portion, indicative of previous section (B**1**) parity error contents of the communication signal **74** prior to its arrival at the first network element **64**. Block **180** then directs the microcontroller **120** to cooperate with the TROHP **88** to insert the contents of the section field of the PTOH register **129** into the STS#**9** time-slot of the K**2** byte for a fourth sub-interval of **25** ms (i.e. for the next **200** successive data frames).

In this embodiment, block **180** continues to direct the microcontroller **120** to insert the PTOH portion **80**, or more particularly, the contents of the PTOH register **129**, into the STS#**9** time-slot of the K**2** byte of the communication signal **74** in the above manner, repeating the above four-part cycle once every **100** ms. Similarly, block **180** continues to direct the microcontroller to sample the contents of the PM binning register **89** once per second and to sample the contents of the signal degrade binning register **91** effectively once every **100** ms (or alternatively, more often), and to update the contents of the section errors register **125**, the line errors register **127**, and the section and line fields of the PTOH register **129**, thereby updating the PTOH portion **80** inserted into

the communication signal **74**, as described above. Block **180** is thus executed indefinitely, as a thread, by the microcontroller **120**.

The communication signal **74**, which in this embodiment is an OC-**48** signal, including the PTOH and PPE portions **80** and **84**, is byte-interleave-multiplexed by the network element **64** into an OC-**192** signal which is transmitted on the network **60** by the transmitter **87** of the first network element **64**. The PTOH portion **80** and the PPE portion **84** are transparently passed through any network elements **68** such as LTEs for example on the network **60**, as the PPE portion is stored in the synchronous payload envelope **164** which is always carried transparently through non-path-terminating elements, and the intervening network elements **68** are configured to transparently pass the unused portion **162** (or more particularly, the unused OC#**9** time-slot of the K**2** bytes) of the transport overhead portion **104**, in which the PTOH portion **80** is stored. In this embodiment, the communication signal **74** is multiplexed into an OC-**192** signal comprising other communication signals that are not to be provided as clear channels. Alternatively, however, as no special dedicated facilities are required in the present embodiment, any desired mixture of clear channel and non-clear channel communication signals may be multiplexed together as desired.

<u>Second Network Element</u>

Referring to Figures **3**, **5**, **7** and **8**, upon arrival at the second network element **66** of the communication signal **74**, as a multiplexed component of the OC-**192** signal transmitted by the first network element **64**, the communication signal **74** is demultiplexed from the OC-**192** signal. Advantageously, in the present embodiment, as dedicated clear channel facilities are not required, the communication signal **74** is demultiplexed from the OC-**192** signal in the same manner that non-clear channels are customarily demultiplexed, without the need to demultiplex the entire OC-**192** signal and re-multiplex the signal components that are not being dropped off at the second network element **66**.

At the second network element **66**, as the communication signal **74** is demultiplexed, the processor circuit **102** of the second network element commences execution of the transport overhead modification thread **138** shown in Figure **8**.

The transport overhead modification thread begins with a first block **200** of codes, which configures the processor circuit **102** to calculate a difference between path errors present in the communication signal **74**, and the path errors **86** that were present in the communication signal at the remote first network element **64**. More particularly, in this embodiment, block **200** configures the processor circuit **102** to calculate such a difference for each payload portion having valid path overhead in the communication signal **74**. Thus, for example, if the communication signal **74** includes a plurality of STS-**1** component signals, block **200** directs the microcontroller **130** to configure the processor circuit **102**, or more particularly the SYDR device **108**, to calculate, for each of the STS-**1** component signals, a difference between path errors present in the STS-**1** component signal and the path errors **86** that were present in the STS-**1** component signal at the remote first network element **64**. Alternatively, if the communication signal **74** includes a plurality of concatenated payloads in respective concatenated STS-nc component signals, it will be appreciated that only the first STS-**1**c subcomponent of each STS-nc component signal (for example, STS#**1**, #**13**, #**25** and #**37** if the STS-**48** communication signal **74** includes four STS-**12**c component signals) will have valid path overhead and accordingly, block **200** directs the microcontroller to configure the SYDR device **108** to calculate such a difference value only for the first such STS-**1**c subcomponent of each STS-nc component signal. For ease of illustration, however, the following discussion focuses primarily on the non-concatenated example in which the communication signal **74** includes non-concatenated STS-**1** component signals.

In this regard, it will be appreciated that conventional TCM functionality at a tandem connection termination equipment (TCTE) such as the second

network element **66**, involves, for each STS-**1** component of the communication signal **74**, re-calculating the number of parity errors present in the SPE portion **164** of the previous STS-**1** component. The contents of the B**3** byte **170** of the current STS-**1** component are then subtracted from this re-calculated number of parity errors over the previous component, to yield the number of path errors present in the previous STS-**1** component of the signal **74** upon its arrival at the TCTE, or in other words, the number of bit errors that have occurred in the SPE **164** of the previous STS-**1** component since the communication signal **74** was initially generated and transmitted by the customer's path originating equipment. A difference between this number of path errors present in the signal **74** at the TCTE, and the number of path errors **86** that were present in the signal **74** at the tandem connection originating (TCO) point (in this embodiment, the first network element **64**) is then calculated. In this regard, it will be recalled that the number of path errors **86** present at the TCO is stored in the first **4** bits of the Z**5** byte **172** according to conventional TCM, and therefore, this difference is calculated by subtracting the contents of the first **4** bits of the Z**5** byte from the number of path errors present in the signal **74** at the TCTE. The magnitude of this difference represents the number of new path errors that occurred in the previous STS-**1** SPE **164** along its journey between the TCO and the TCTE. The TCTE then records this value for network monitoring purposes, resets the first **4** bits of the Z**5** byte **172** to zeroes, and compensates the B**3** byte **170** to account for the parity change resulting from this resetting.

Accordingly, referring to Figures **3**, **5**, **6**, **7** and **8**, if block **150** of the PTOH and PPE insertion thread **128** shown in Figure **6** configured the processor circuit **78** to insert the PPE portion **84** into the Z**5** byte **172** in the same manner as a conventional TCO element, then similarly, block **200** of the transport overhead modification thread **138** would configure the processor circuit **102** to calculate such difference values in the same manner as a conventional TCTE.

However, as noted, in the present embodiment block **150** of the PTOH and PPE insertion thread **128** configures the processor circuit **78** to insert the

number of path errors **86** into the Z**3** byte **174** (or alternatively, the Z**4** byte **176**) rather than the Z**5** byte **172**. Accordingly, in the present embodiment block **200** of the transport overhead modification thread **138** directs the microcontroller **130** to configure the SYDR device **108** to calculate the difference values by, for each STS-**1** component, subtracting the contents of the first **4** bits of the Z**3** byte **174** (or alternatively, of the Z**4** byte **176**) rather than of the Z**5** byte **172**, from the number of path errors present in the previous STS-**1** component at the second network element **66**. Similarly, rather than resetting the first **4** bits of the Z**5** byte, block **150** configures the processor circuit **102** to reset the first **4** bits of the Z**3** byte **174** (or alternatively the Z**4** byte **176**), and to compensate the B**3** byte for the resulting parity change. Advantageously, therefore, if the customer who supplied the communication signal **74** is attempting to use the Z**5** (or N**1**) bytes **172** to perform TCM between points on his own facilities, the customer's ability to do so will not be destroyed, as the present embodiment does not involve any modifications to the Z**5** byte at all over the network **60**.

Once configured in this manner at block **200**, the SYDR device **108** continuously calculates difference values in the above manner and continuously provides signals representing such values to the microcontroller **130**. Thus, in this embodiment the TCM calculations at the second network element **66** are also performed by hardware, namely the SYDR device **108**. Alternatively, however, software-simulated TCM may be substituted if desired.

Referring to Figures **3**, **5**, **7** and **8**, block **210** then configures the processor circuit **102** to calculate a sum of the differences of each of the component signals. To achieve this, block **210** directs the microcontroller **130** to receive the signals from the SYDR device **108** representing the difference value (described above in connection with block **200**) for each of the **48** STS-**1** components of each STS-**48** signal, and to store such values in the differences register **202** in the second working memory **134**. Block **210** further directs the microcontroller **130** to maintain a sum of the difference values in the sum of differences register **203**. In this embodiment, the

difference values are collected from the SYDR device **108** once per second, and a sum of differences is calculated over each such collected set of difference values. The sum of differences, which represents the total number of new path parity errors produced in the communication signal **74** during the course of its voyage between the first and second network elements **64** and **66** over a one-second interval, is then divided by ten, to produce an average sum of differences value over each **100** ms sub-interval. (It will be recalled that this **100** ms sub-interval is the same duration of sub-interval as that over which the PTOH portion **80**, which was inserted into the communication signal **74** at the first network element **64**, was calculated. Accordingly, it is desirable to divide the sum of differences by ten in this manner so that the sum of differences is effectively calculated over the same duration of time interval as the PTOH portion **80**.) The result of such division is stored in the sum of differences register **203**. Thus, in the present embodiment, the contents of the sum of differences register **203** are updated once every second, but correspond to an average sum of difference values over each **100** ms time interval in the preceding second. Alternatively, however, the sum of differences register **203** may be updated more or less frequently if desired.

In addition, referring to Figures **3** to **8**, block **210** directs the microcontroller **130** to cooperate with the TROHP **106** to begin continuously extracting the PTOH portion **80** stored in the unused transport overhead portion **162** of the communication signal **74**. In this embodiment, such continuous monitoring and extraction of the PTOH portion **80** is achieved in a **100** ms four-part cycle consisting of four **25** ms sub-intervals, corresponding to the four-part cycle described above in connection with block **180** at the first network element **64**.

In this regard, block **210** first directs the microcontroller **130** to cooperate with the TROHP **106** to monitor the contents of the STS#**9** time-slot of the K**2** byte of the communication signal **74**. Upon detecting the presence of the unique B**2** header value in this STS#**9** time-slot, block **210** directs the microcontroller **130** to continue to monitor the K**2** STS#**9** time-slot of the communication

signal until a byte other than the unique B**2** header value is detected. Upon detecting such a byte, if the byte represents a raw line error value less than **126**, as described above in connection with block **180**, block **210** directs the microcontroller **130** to copy the byte into the previous line overhead field **206** of the PTOH register **204**. Alternatively, if the detected byte represents a line error index value as described in connection with Table **1** above, block **210** directs the microcontroller **130** to use the index value byte to search the reverse index look-up table **142**, to extract an approximated line error count value corresponding to the detected byte. In this regard, the reverse index look-up table **142** is similar to a reverse of the index look-up table **123** shown in Table **1** above, but provides a single average or approximated error count value (rather than a range of error count values) corresponding to each index value. Block **210** then directs the microcontroller **130** to store the located approximated error count value in the previous line overhead field **206** of the PTOH register **204**.

Block **210** then directs the microcontroller **130** to cooperate with the TROHP **106** to continue monitoring the contents of the STS#**9** time-slot of the K**2** byte of the communication signal **74**. Upon detecting the presence of the unique B**1** header value in this STS#**9** time-slot, block **210** directs the microcontroller **130** to continue to monitor the K**2** STS#**9** time-slot of the communication signal until a byte other than the unique B**1** header value is detected. Upon detecting such a byte, if the byte represents a raw section error value less than **126**, as described above in connection with block **180**, block **210** directs the microcontroller **130** to copy the byte into the previous section overhead field **205** of the PTOH register **204**. Alternatively, if the detected byte represents a section error index value as described in connection with Table **1** above, block **210** directs the microcontroller **130** to use the index value byte to search the reverse index look-up table **142**, to locate and extract an approximated error count value corresponding to the detected section error index value byte. Block **210** then directs the microcontroller **130** to store the located approximated error count value in the previous section overhead field **205** of the PTOH register **204**.

Block **210** further directs the microcontroller **130** to continuously monitor the **K2** STS**#9** time-slot as indicated in the preceding two paragraphs, to continuously extract the PTOH portion **80**, and to store corresponding line and section error values in the previous line and section overhead fields **206** and **205** respectively as described above.

Block **210** further configures the processor circuit **102** to modify the transport overhead portion **104** of the communication signal **74**, in response to the extracted PTOH and PPE portions **80** and **84**. More particularly, in this embodiment block **210** configures the processor circuit to adjust the transport overhead portion **104** in response to a sum of at least some contents of the PTOH portion plus the sum of differences value stored in the sum of differences register **203**.

In this embodiment, block **210** achieves this by directing the microcontroller **130** to add the contents of the sum of differences register **203** to the contents of the previous section overhead field **205**, and to store the resulting value in the outgoing section error register **207**. If desired, this resulting value may be "massaged", by rounding it up to the nearest multiple of eight for example, prior to storing it in the outgoing section error register **207**. As noted, such massaging may be useful if the TROHP **106** is constrained in its ability to corrupt certain numbers of bits in the outgoing communication signal.

If the contents of the outgoing section error register **207** are less than **126**, block **210** directs the microcontroller **130** to use the contents of the outgoing section error register **207** to locate a corresponding record in the hardware configuration look-up table **144**, to look up register configurations of the TROHP **106** that must be implemented in order to invert bits of the B**1** section parity error bytes of the transport overhead portion **104** of the outgoing communication signal **74**, to effectively simulate a bit error count over a **100** ms interval equivalent to the contents of the outgoing section error register **207**. In this regard, it will be appreciated that typical TROHP ASICs will have the ability, for diagnostic purposes, to invert certain bits of transport overhead, such as inverting one bit or all bits, of a single B**1** or B**2** byte, of all B**2** bytes in

a frame, or of all B1 or B2 bytes over a given number of frames, for example. Thus, the particular register configuration addresses and values stored in the hardware configuration look-up table **144** are dependent upon the make and model of the particular TROHP ASIC used, and will vary from ASIC to ASIC. Upon locating the hardware configuration look-up table record corresponding to the contents of the outgoing section error register **207**, block **210** directs the microcontroller **130** to set the relevant register configurations of the TROHP **106** in accordance with the located record, to invert an appropriate number of bits of an appropriate number of B**1** section parity error bytes to simulate an outgoing error rate equivalent to the error count value stored in the outgoing section error register over a **100** ms interval.

Similarly, if the contents of the outgoing section error register **207** are greater than or equal to **126**, block **210** directs the microcontroller **130** to use the contents of the outgoing section error register **207** to locate a corresponding index value in the forward index look-up table **140**. In this embodiment, the forward index look-up table **140** is identical to the index lookup table **123**, shown as Table **1** above. Block **210** then directs the microcontroller to use the located index value to look up a corresponding hardware configuration record in the hardware configuration look-up table **144**, to look up register configurations of the TROHP **106** that must be implemented in order to invert bits of the B**1** section error bytes of the transport overhead portion **104** of the outgoing communication signal **74**, to effectively simulate a bit error rate over a **100** ms interval equivalent to the bit error rate corresponding to the index value that corresponds to the contents of the outgoing section error register **207** (see Table **1** above). The microcontroller is then directed to set such register contents of the TROHP in accordance with the located record.

In addition, block **210** configures the processor circuit **102** to further modify the transport overhead portion **104** of the outgoing communication signal **74**, by adjusting B**2** line parity error bytes thereof. More particularly, block **210** directs the microcontroller **130** to add the contents of the sum of differences register **203** to the contents of the previous line overhead field **206**, and to

store the resulting value in the outgoing line error register **208**. As discussed in connection with the outgoing section error register, if desired, this resulting value may be "massaged", by rounding it up to the nearest multiple of eight for example, prior to storing it in the outgoing line error register **207**.

If the contents of the outgoing line error register **208** are less than **126**, block **210** directs the microcontroller **130** to use the contents of the outgoing line error register **208** to locate a corresponding record in the hardware configuration look-up table **144**, to look up register configurations of the TROHP **106** that must be implemented in order to invert bits of the B**2** line parity error bytes of the transport overhead portion **104** of the outgoing communication signal **74**, to effectively simulate a bit error count over a **100** ms interval equivalent to the contents of the outgoing line error register **208**. Upon locating the hardware configuration look-up table record corresponding to the contents of the outgoing line error register **208**, block **210** directs the microcontroller **130** to set the relevant register configurations of the TROHP **106** in accordance with the located record, to invert an appropriate number of bits of an appropriate number of B**2** line parity error bytes to simulate an outgoing error rate equivalent to the error count value stored in the outgoing line error register over a **100** ms interval.

Similarly, if the contents of the outgoing line error register **208** are greater than or equal to **126**, block **210** directs the microcontroller **130** to use the contents of the outgoing line error register **208** to locate a corresponding index value in the forward index look-up table **140**. Block **210** then directs the microcontroller to use the located index value to look up a corresponding hardware configuration record in the hardware configuration look-up table **144**, to look up register configurations of the TROHP **106** that must be implemented in order to invert bits of the B**2** line parity error bytes of the transport overhead portion **104** of the outgoing communication signal **74**, to effectively simulate a bit error rate over a **100** ms interval equivalent to the bit error rate corresponding to the index value that corresponds to the contents of the outgoing line error register **208** (see Table **1** above). The microcontroller

is then directed to set such register contents of the TROHP in accordance with the located record.

Block **210** continues to direct the processor circuit **102** to modify transport overhead bytes of the outgoing communication signal **74** in the above manner indefinitely, executed as a thread at the microcontroller **130**.

Thus, referring back to Figure **3**, it will be appreciated that as a result of the execution of the transport overhead modification thread, a clear channel has effectively been provided across a segment of the network extending from the first network element **64** to the second network element **66**.

For example, if new payload or path errors are being generated on the optical pipe **72**, or more generally, in any stretch of the customer's equipment lying between the customer's last section- or line-terminating equipment prior to the first network element **64**, then without the clear channel provided by the present embodiment, the customer would not have been able to detect such errors at the second customer equipment **98** for example, as the relevant B**1** and B**2** section and line overhead bytes would have been erased and regenerated by various STEs and LTEs on the network **60**, including the first and second network elements **64** and **66** and various elements therebetween. The customer would not have been able to detect such errors until arrival of the communication signal **74** at the customer's path-terminating equipment, at which point the customer would not have any information as to the location along the path where such errors occurred.

In accordance with the present embodiment of the invention, however, the B**1** and B**2** bytes of the outgoing communication signal **74** transmitted from the second network element **66** have been modified, to simulate, for error preservation purposes, the effects that would have occurred if the original transport overhead contents **82** had been transparently passed through the network **60** and had been adjusted to compensate for any path errors that may have occurred on the network **60**, to further enhance such transparency.

For example, if path errors were occurring at an average rate of **40** errors per **100** ms over the network **60**, the B**2** bytes and B**1** bytes of the outgoing communication signal **74** transmitted from the second network element **66**, as a result of the addition of the contents of the sum of differences register **203** to the reconstructed previous section and line overhead fields **205** and **206** as discussed above, are effectively adjusted to compensate for the new path errors: the new path errors produce new parity errors, but the B**1** and B**2** bytes are also incremented to account for the new parity errors, so that any downstream equipment counting the number of parity errors will not, on average, detect any discrepancy between the counted number of parity errors and the expected number (B**1** or B**2**) of parity errors. Accordingly, these path errors on the network **60** do not, on average, result in any section or line error alarms at the second customer equipment **98** (although path errors would ultimately be detected at the path terminating equipment).

However, if in addition to these path errors occurring on the network **60**, an average of **80** path or payload errors per **100** ms were occurring on the optical pipe **72** prior to arrival at the first network element **64**, these errors would not be reflected in the sum of differences values added to the reconstructed previous section and line overhead fields **205** and **206**. Therefore, by adjusting the outgoing B**1** and B**2** bytes produced at the second network element **66** in response to the previous section and line overhead fields **205** and **206**, the outgoing B**1** and B**2** bytes mimic the effect of the original B**1** and B**2** bytes received at the first network element **64**, so that on average, the values of the outgoing B**1** and B**2** bytes will differ from the actual counted number of section and line parity errors, by a rate equivalent to the rate at which the errors are occurring on the optical pipe **72**. Accordingly, when the outgoing signal **74** produced by the second network element **66** arrives at the second customer equipment **98**, these errors trigger section error alarms and/or line error alarms, depending on whether the equipment **98** is both an STE and an LTE, indicative of an average parity bit error rate of approximately **80** errors per **100** ms.

Therefore, from the customer's point of view, in terms of the customer's ability to detect section and line errors on the customer's equipment, it is as if the network **60** and all the various LTEs and STEs therein did not exist, and the optical pipe **72** was connected directly to the optical pipe **96** shown in Figure **3**.

Alternatives

Although in the foregoing embodiment, the PPE portion **84** was described as having been inserted into and extracted out of the communication signal **74** by hardware (the SYDR devices **90** and **108**), alternatively, a similar variation of TCM may be simulated with appropriate software if desired. Similarly, although the PTOH portion **80** was described as having been inserted into and extracted from the communication signal **74** by the execution of software, alternatively, if suitable hardware is available, the insertion and extraction of the PTOH portion may be carried out by such hardware. Depending on the configurations of such hardware, variations in the nature of the PTOH portion to more closely approximate or equal the original transport overhead contents **82** (B**1** and B**2**) may be implemented.

Likewise, although the modification of the transport overhead portion **104** of the outgoing communication signal **74** in response to the PTOH and PPE portions was described as having been implemented through the execution of software in combination with hardware, alternatively, such modification may be accomplished through hardware alone. It will be appreciated that such hardware, in combination with hardware for extracting the PTOH portion **80**, may be capable of more refined modifications of the outgoing B**1** and B**2** bytes of the transport overhead portion **104**, involving, for example, a more selective modification of individual B**1** and B**2** bytes, resulting in further enhanced transparency, with reduced or eliminated frame delay.

In addition, it will be appreciated from the foregoing that the methods described above for calculating, inserting and extracting the PTOH portion **80** are merely one example of simulating or approximating the effects of

transparent passage through the network **80** of the original B**1** and B**2** bytes of the incoming transport overhead contents **82**. Alternatively, other suitable simulation, approximation or transparency methods may be substituted.

More generally, while specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.